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REVIEW ARTICLE

Solanum torvum Sw.: Bioactive Phytochemicals and Molecular Mechanisms, Therapeutic Potential, and Pharmaceutical Translation

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Abstract

Solanum torvum Sw. (Turkey berry) is a medicinal plant widely consumed as a functional food and traditionally used to treat diabetes, inflammatory disorders, microbial infections, liver diseases, anemia, and other chronic ailments. Increasing evidence highlights its rich phytochemical composition and broad pharmacological potential; however, a comprehensive synthesis linking phytochemicals with molecular mechanisms and pharmaceutical translation remains limited. This review critically evaluates the taxonomy, phytochemical diversity, pharmacological activities, toxicological profile, and translational prospects of *S. torvum* Sw. The plant contains diverse bioactive constituents, including steroidal glycoalkaloids (solasonine, solamargine, solasodine, and torvosides), phenolic acids, flavonoids, terpenoids, saponins, and tannins, which modulate oxidative stress, inflammation, apoptosis, ferroptosis, mitochondrial dysfunction, and signaling pathways such as nuclear factor-kappa, Nrf2, PI3K/Akt, STAT3, p53, and glutathione peroxidase 4. Preclinical studies support antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, cardioprotective, nephroprotective, neuroprotective, antiviral, and anticancer activities. Nevertheless, pharmaceutical development is limited by phytochemical variability, insufficient pharmacokinetic and toxicological data, inadequate compound-specific mechanistic validation, and the lack of robust clinical trials. Future studies should emphasize standardized phytochemical profiling, metabolomics, molecular target validation, pharmacokinetic characterization, and clinical investigations to accelerate the development of evidence-based phytopharmaceuticals and nutraceuticals from *S. torvum* Sw.

Key words: Bioactive phytochemicals, drug discovery, molecular pharmacology, pharmaceutical translation, pharmacological activities, phytopharmaceuticals, *Solanum torvum* Sw., steroidal glycoalkaloids

INTRODUCTION

Solanum torvum Swartz (Turkey berry), a member of the family Solanaceae, is an important medicinal plant widely distributed across Asia, Africa, and tropical America. It has attracted considerable scientific interest due to its rich phytochemical composition, nutritional value, and long-standing use in traditional medicine.[1,2] Different parts of the plant, including the fruits, leaves, roots, and stems, have traditionally been used to manage diabetes, hypertension, inflammatory disorders, microbial infections, gastrointestinal diseases, liver ailments, anemia, and several other health conditions.[3,4] Increasing experimental

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evidence further demonstrates that *S. torvum* Sw. possesses antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, cardioprotective, nephroprotective, neuroprotective, and anticancer activities, highlighting its value as both a medicinal plant and a functional food.[5,6]

The broad therapeutic potential of *S. torvum* Sw. is primarily attributed to its diverse repertoire of secondary metabolites, including steroidal glycoalkaloids (SGA), phenolic acids, flavonoids, saponins, terpenoids, tannins, and other phenolic compounds.[7,8] Advances in chromatographic and spectroscopic techniques have enabled the characterization of numerous bioactive constituents, such as solasonine, solamargine, solasodine, torvosides, chlorogenic acid (CGA), gallic acid, caffeic acid, quercetin, kaempferol, and rutin. These compounds exert pharmacological effects through modulation of oxidative stress, inflammation, apoptosis, ferroptosis, mitochondrial dysfunction, and multiple cell-signaling pathways.[9-12]

Although several reviews have summarized the ethnomedicinal uses, phytochemistry, and pharmacological properties of *S. torvum* Sw., a comprehensive synthesis linking individual phytochemicals with their quantitative occurrence, molecular mechanisms, pharmacological evidence, toxicological profile, and translational relevance is still lacking.[1,2,5,6,13] Moreover, limited information is available on compound-specific pharmacokinetics, bioavailability, molecular targets, phytochemical standardization, and clinical validation, which continues to impede the pharmaceutical development of *S. torvum* Sw. derived bioactive compounds.[2,12]

This review provides a comprehensive and critical evaluation of the phytochemical constituents of *S. torvum* Sw., with particular emphasis on their occurrence, pharmacological activities, molecular mechanisms, and therapeutic significance. In contrast to previous reviews, it integrates recent evidence on major phytochemical classes while critically examining compound-specific mechanisms of action, toxicological aspects, current research gaps, and future priorities for pharmaceutical translation. By consolidating contemporary knowledge and identifying unresolved challenges, this review aims to establish a robust scientific foundation for future phytochemical research and to support the development of *S. torvum* Sw. based phytopharmaceuticals, nutraceuticals, and functional foods.[5,6]

BOTANY AND TAXONOMY CLASSIFICATION

Taxonomic classification

S. torvum Sw., a member of the family Solanaceae, was first described by Olof Swartz in 1788 in Nova Genera et Species *Plantarum*. It belongs to the Old-World *Solanum* clade and section *Acanthophora*. Reported synonyms include *Solanum ficifolium* Ortega, *S. torvum* var. *vaillantii* Dunal, and *S. torvum* var. *ecuadorense*. The taxonomic classification and key biological characteristics of *S. torvum* Sw. are summarized in Table 1.

Botanical description

S. torvum Sw. is an erect, much-branched, monoecious perennial shrub that typically grows 1–3 m in height under favorable conditions. The stems are terete, densely covered with stellate hairs, and armed with recurved pale-yellow prickles measuring 3–8 mm in length. Leaves are arranged alternately and are ovate to broadly elliptic (10–20 × 6–14 cm), with deeply sinuate or pinnately lobed margins bearing 3–5 pairs of lateral lobes. Both leaf surfaces are densely stellate-pubescent, while the midrib and veins are

Table 1: Taxonomic classification and key biological characteristics of *Solanum torvum* Sw.

Taxonomic rank	Classification
Kingdom	Plantae
Phylum (Division)	Tracheophyta (Angiosperms)
Class	Magnoliopsida (Eudicots)
Order	Solanales
Family	Solanaceae
Genus	*Solanum* L.
Species	*Solanum torvum* Sw.
Common name	Turkey berry, Devil's fig, Pea eggplant
Plant habit	Erect, perennial, prickly shrub
Height	1–3 m
Stem	Terete, stellate-pubescent, armed with recurved prickles
Leaves	Alternate, ovate to broadly elliptic, sinuate- to pinnately lobed, stellate-pubescent
Inflorescence	Lateral, extra-axillary corymbs with white stellate flowers
Fruit	Globose berry (1–1.5 cm), borne in clusters, green when immature and yellowish-orange to red at maturity
Seeds	Numerous (100–200 per fruit), discoid, yellowish-brown, ~2 mm diameter
Chromosome number	$2n=24$
Native distribution	Caribbean and tropical Central and South America
Present distribution	Widely naturalized throughout tropical and subtropical Africa, Asia, the Pacific Islands, and the Americas
Ecological preference	Thrives from sea level to ~1,800 m; tolerates 15–38°C, 600–2,500 mm annual rainfall, and a wide range of soil types

prickly. The inflorescences are lateral, extra-axillary corymbs composed of 10–20 white, stellate flowers, each measuring 2–3 cm in diameter and arranged in dichasial clusters. The fruits are globose berries (1–1.5 cm in diameter) borne in grape-like clusters containing 20–40 fruits. Immature fruits are green with pale longitudinal stripes and gradually ripen to yellowish-orange before turning red. Each fruit contains 100–200 discoid, yellowish-brown seeds, approximately 2 mm in diameter.[2]

PHYTOCHEMICAL CONSTITUENTS OF *S. TORVUM* SW.

S. torvum Sw. is a rich source of bioactive phytochemicals, including alkaloids, flavonoids, saponins, steroids, tannins, terpenoids, and phenolic compounds, identified from both aqueous and organic extracts.[7] The major phytochemical constituents of *S. torvum* Sw. are summarized in Figure 1. Their abundance is influenced by genotype, plant organ, developmental stage, environmental conditions, and extraction method, indicating considerable phytochemical variability. Qualitative analyses using thin-layer chromatography and high performance liquid chromatography (HPLC) further reveal organ-specific metabolite distribution. Leaves generally accumulate higher levels of phenolic compounds, alkaloids, and overall phenolics, whereas fruits are comparatively richer in flavonoids and saponins.[8] This differential distribution suggests tissue-specific biosynthesis and highlights the importance of selecting appropriate plant parts for targeted therapeutic applications. The pharmacological efficacy of *S. torvum* Sw, particularly its reported neuroprotective activity, is therefore attributed to the synergistic interaction of multiple phytochemical classes that collectively modulate oxidative stress, neuroinflammation, mitochondrial dysfunction, excitotoxicity, and apoptosis.[14] Overall, the phytochemical complexity of *S. torvum* Sw. provides a strong basis for its medicinal potential; however, variations in metabolite composition among plant organs, genotypes, and extraction protocols limit reproducibility and cross-study comparisons. Standardized phytochemical profiling, quantitative metabolomics, and bioactivity-guided isolation are therefore essential to identify key bioactive constituents and accelerate its translation into evidence-based pharmaceutical applications. The major pharmacological activities of *S. torvum* Sw. are summarized in Figure 2.

SGAs

SGAs are one of the major bioactive constituents of *Solanum* species. Structurally, they consist of a nitrogen-containing steroidal aglycone linked to one or more glycoside residues. To date, 107 SGAs have been identified, many of which exhibit diverse pharmacological activities, including cytotoxic, antimicrobial, and anti-cholesterol effects.[12] Their biosynthesis begins with cholesterol, which is produced through tightly regulated enzymatic reactions linking primary sterol metabolism with specialized secondary metabolic pathways.[15] In *Solanum* species, cholesterol is subsequently converted into steroidal aglycones, followed by glycosylation at the C-3 hydroxyl group to generate SGAs. In plants, these metabolites function primarily as chemical defenses against insects, fungi, nematodes, and herbivores. Beyond their ecological role, accumulating evidence demonstrates that SGAs possess important pharmacological properties, particularly in the management of neurological disorders, highlighting their potential as promising therapeutic candidates.[11] The major SGAs identified in *S. torvum* Sw. are summarized in Figure 1.

Solasonine

Solasonine is a SGA reported in *S. torvum* Sw. at a relatively low concentration (0.0043%). Although its specific pharmacological effects have not yet been directly characterized in *S. torvum* Sw., extensive studies on purified solasonine and other *Solanum* species demonstrate broad

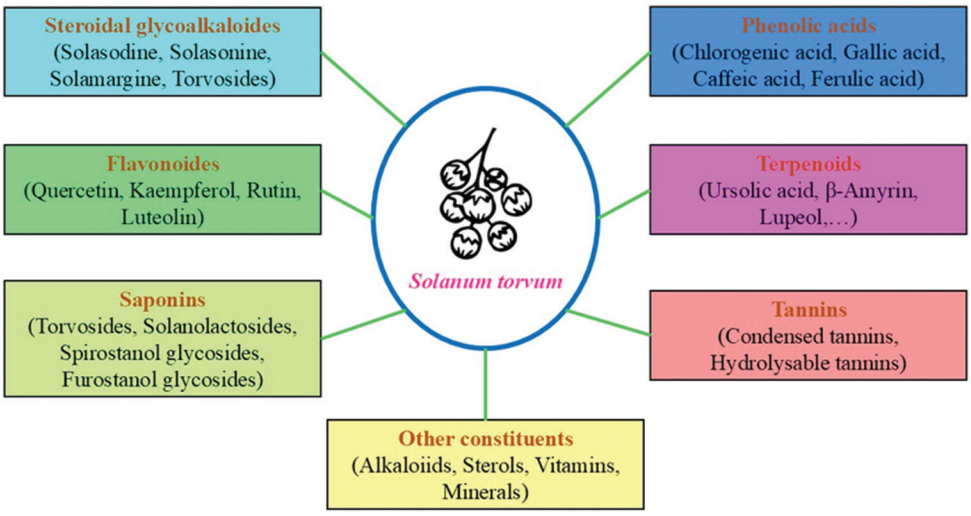


Figure 1: Major phytochemical constituents of *Solanum torvum* Sw.

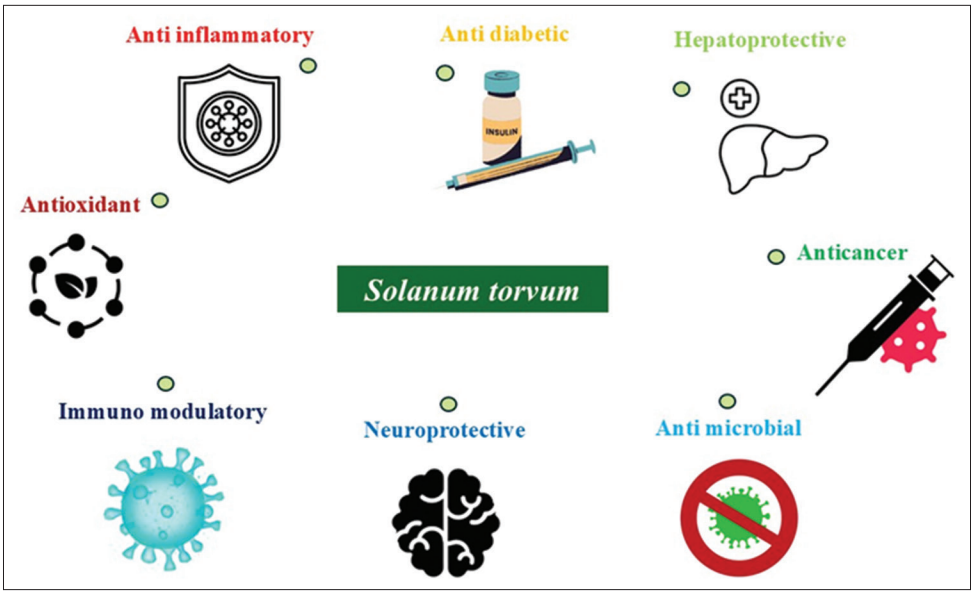


Figure 2: Pharmacological profile of *Solanum torvum* Sw.

therapeutic potential. Solasonine exerts potent anticancer activity by suppressing cancer cell proliferation, inducing G2-phase cell cycle arrest, and promoting apoptosis through endoplasmic reticulum stress and mitochondrial apoptotic pathways. These effects are associated with modulation of apoptosis-related proteins, including downregulation of Bcl-2, Bcl-xL, Bax, and caspase-3.[16] It also disrupts the mortalin–p53 interaction, facilitating nuclear translocation of p53 and thereby enhancing apoptosis and cancer cell death.[17] Furthermore, solasonine inhibits tumor growth and colony formation while increasing chemosensitivity through regulation of the miR-486-5p/PIK3R1 signaling axis.[18] In hepatocellular carcinoma, it suppresses cell proliferation, migration, invasion, and tumor growth by inhibiting glutathione peroxidase 4- and GSS-mediated glutathione redox pathways, thereby promoting ferroptosis.[19] More recently, solasonine has been shown to inhibit non-small-cell lung cancer metastasis through suppression of the threonine tyrosine kinase/GATM/Smad2 signaling pathway.[20] Collectively, these findings establish solasonine as a multifunctional bioactive compound with significant anticancer potential through the regulation of apoptosis, ferroptosis, metastasis, and chemosensitivity. However, despite the presence of solasonine in *S. torvum* Sw., its compound-specific pharmacological effects and molecular mechanisms have not yet been experimentally validated in this species. Future studies should therefore focus on isolating solasonine from *S. torvum* Sw. and elucidating its biological activities to substantiate its contribution to the plant's medicinal properties.

Solamargine

Solamargine is a major SGA present in *S. torvum* Sw. at approximately 0.0028%. It exhibits a broad spectrum of pharmacological activities, including antioxidant, antimicrobial, antifungal, anti-inflammatory, analgesic, antiulcer, antihypertensive, antidiabetic, nephroprotective, cardioprotective, and immunomodulatory effects.[5] Beyond these activities, solamargine has attracted considerable attention for its potent anticancer properties. Evidence from studies on purified solamargine indicates that it modulates multiple signaling networks involved in cell survival, tumor suppressor function, caspase activation, mitochondrial apoptosis, death receptor signaling, protein kinase regulation, and other cancer-associated pathways.[21] In addition, solamargine has demonstrated significant antineoplastic activity by inhibiting the proliferation of several tumor cell lines and suppressing tumor growth in experimental liver cancer and Ehrlich ascites tumor models.[22] Although these findings highlight the therapeutic potential of solamargine, its compound-specific pharmacological effects and molecular mechanisms have not yet been directly validated in *S. torvum* Sw. Therefore, isolation of solamargine from *S. torvum* Sw. and mechanistic studies are required to establish its precise contribution to the medicinal properties of this species.

Solasodine

Solasodine is the steroidal aglycone precursor of glycoalkaloids such as solasonine and solamargine and is present in *S. torvum* Sw. leaves and fruits at approximately 0.0043% as part of these glycosylated derivatives.[4] It is recognized as an important therapeutic constituent with reported analgesic and anti-inflammatory properties. Experimental evidence further indicates that solasodine-derived glycoalkaloids can inhibit cardiac contraction and modulate smooth muscle activity in the ileum and trachea, possibly through interactions with acetylcholine-mediated signaling.[1] However, these biological effects have largely been attributed to solasonine and related glycoalkaloids rather than free solasodine. Consequently, the specific pharmacological role and molecular mechanisms of solasodine in *S. torvum* Sw. remain poorly understood. Further studies focusing on its isolation, quantification, and

mechanistic evaluation are needed to clarify its therapeutic significance.

Torvosides

Torvosides represent a unique group of steroidal glycosides characteristic of *S. torvum* Sw., including Torvosides A–N, Torvoside H, Torvanol A, and Solanolactosides A and B.[1] Several members, including Torvosides H, A, M, and N, have been associated with diverse pharmacological activities such as antioxidant, antimicrobial, antiviral, anti-inflammatory, analgesic, antiulcer, antihypertensive, antidiabetic, cardioprotective, hepatoprotective, nephroprotective, antimalarial, anthelmintic, immunoprotected, and anticancer effects.[4] Antiviral activity has been specifically reported for Torvanol A, Torvoside H, and related compounds isolated from *S. torvum* Sw. fruits.[23] In addition, Torvosides J, K, and L have been chemically characterized from the fruits using fast atom bombardment mass spectrometry and nuclear magnetic resonance spectroscopy, confirming the structural diversity of this glycoside family.[24] Traditional medicinal applications of *S. torvum* Sw. fruits, leaves, and roots for treating liver disorders, cough, sore throat, epilepsy, diarrhea, diabetes, skin diseases, toothache, and other ailments have also been attributed, in part, to these glycoalkaloids together with saponins, anthocyanins, and isoflavonoids.[3] Despite their broad biological potential, the molecular mechanisms underlying torvoside activity remain largely unexplored. Their structural similarity to other SGAs suggests possible roles in reducing oxidative stress, suppressing inflammatory mediators, and stabilizing cellular membranes. However, direct molecular targets and pharmacological mechanisms, particularly in neurological disorders, have yet to be established, highlighting an important area for future investigation.

Phenolic compounds

Phenolic acids represent another major class of bioactive phytochemicals in *S. torvum* Sw. These compounds possess one or more hydroxyl groups attached to aromatic rings, enabling efficient hydrogen or electron donation to neutralize reactive oxygen species. This structural feature underpins their strong antioxidant capacity and contributes to the plant's pharmacological potential.[10] The major phenolic constituents of *S. torvum* Sw. are summarized in Figure 1.

CGA

CGA is an important phenolic acid with well-documented antioxidant, anti-inflammatory, antidiabetic, anticancer, anti-obesity, antimicrobial, cardioprotective, and neuroprotective activities. Its concentration is influenced by plant species, genotype, harvest stage, plant organ, and geographical origin, while HPLC is considered a reliable method for its quantification and quality control. In related *Solanum* species, CGA concentrations of 1.51 g/kg in *Solanum aethiopicum*, 1.66 g/kg in *S. macrocarpon*, and up to 4.87 g/kg in wild *Solanum dasyphyllum* fruit flesh have been reported.[25] However, despite the recognized medicinal importance of CGA, its concentration and pharmacological role have not yet been characterized in *S. torvum* Sw, highlighting a significant gap in the current literature.

Gallic acid

Gallic acid is one of the predominant phenolic acids identified in *S. torvum* Sw. Quantitative analyses have reported concentrations of 1394 ± 25.0 µg/g in aqueous extracts and 598 ± 54.0 µg/g in methanolic extracts.[9] Fruit extracts contain 16.4 mg gallic acid equivalent/g extract, whereas methanolic extracts of raw and boiled berries contain 0.99 mg/kg and 0.71 mg/kg, respectively.[26,27] *In vitro* studies demonstrate that gallic acid exhibits potent antioxidant activity by scavenging free radicals, reducing oxidative stress, and protecting cellular membranes through inhibition of oxidative hemolysis and lipid peroxidation.[9] These findings suggest that gallic acid is a major contributor to the antioxidant properties of *S. torvum* Sw.

Caffeic acid

Caffeic acid has been identified in *S. torvum* Sw. fruits at a concentration of 12.03% (w/w).[10] Although compound-specific pharmacological studies in *S. torvum* Sw. are currently unavailable, caffeic acid is widely recognized for its antioxidant activity through efficient free radical scavenging and oxidative stress reduction. It is therefore likely to contribute to the overall antioxidant potential of the plant.

Ferulic acid

Ferulic acid has been detected in the ethanolic fruit extract of *S. torvum* Sw. at a concentration of 32 ± 5.94 µg/g.[9] As a naturally occurring phenolic acid, it is known to possess strong antioxidant properties and may contribute to the protective effects of *S. torvum* Sw. against oxidative damage. Nevertheless, the pharmacological significance and molecular mechanisms of ferulic acid in *S. torvum* Sw. remain largely unexplored, warranting further bioactivity-guided and mechanistic investigations.

Flavonoids

Flavonoids represent one of the largest and most diverse classes of plant secondary metabolites in *S. torvum* Sw. Structurally, they are polyphenolic compounds possessing a characteristic C6–C3–C6 carbon skeleton and are classified into several subclasses, including flavanols, flavones, flavanones, flavan-3-ols, anthocyanins, isoflavones, and chalcones.[28,29] In plants, flavonoids play essential roles in growth, pigmentation, ultraviolet protection, reproduction, and defense against biotic and abiotic stresses. Beyond these physiological functions, they are recognized as major bioactive constituents responsible for many of the therapeutic

properties of medicinal plants. Flavonoids exhibit a wide range of pharmacological activities, including antioxidant, anti-inflammatory, antimicrobial, antiviral, antidiabetic, cardioprotective, neuroprotective, and anticancer effects. These biological activities are primarily mediated through free radical scavenging, metal ion chelation, modulation of enzyme activity, and regulation of multiple signaling pathways involved in oxidative stress, inflammation, and apoptosis.[28-30] Collectively, the structural diversity and multifunctional biological properties of flavonoids make them key contributors to the medicinal value of *S. torvum* Sw. and promising candidates for the development of phytopharmaceuticals, nutraceuticals, and functional foods. The principal flavonoids reported in *S. torvum* Sw. are summarized in Figure 1.

Quercetin

Quercetin is one of the predominant flavanols identified in *S. torvum* Sw., with a reported concentration of 22.8 mg/g.[31] It exhibits a broad spectrum of pharmacological activities, primarily mediated through its potent antioxidant and anti-inflammatory properties. Quercetin effectively scavenges reactive oxygen species, reduces oxidative stress, chelates metal ions, and protects cells from oxidative damage, thereby preserving cellular homeostasis.[32,33] It also suppresses inflammatory responses by inhibiting pro-inflammatory cytokines and enzymes, reducing the expression of VCAM-1, E-selectin, C-reactive protein, interleukin-1R, Ccl8, IKK, and STAT3, and attenuating nuclear factor kappa (NF-κB) signaling, collectively contributing to reduce vascular inflammation and atherosclerotic lesion development.[34] In addition, quercetin inhibits cancer cell proliferation, induces apoptosis, and enhances normal cell survival, highlighting its promising anticancer potential.[32,33] Beyond these effects, quercetin demonstrates cardioprotective, antihypertensive, antidiabetic, antimicrobial, antifungal, antiviral, anti-obesity, anti-allergic, anti-asthmatic, and neuroprotective activities. These multifunctional properties have also been associated with protection against osteoporosis, cardiovascular and pulmonary diseases, aging, and neurodegenerative disorders, including Alzheimer's disease.[32,35] Overall, quercetin is likely to be a major contributor to the therapeutic potential of *S. torvum* Sw. However, most pharmacological evidence is derived from studies on isolated quercetin rather than *S. torvum* Sw. derived quercetin. Therefore, compound-specific studies are needed to validate its bioavailability, molecular mechanisms, and therapeutic efficacy within this medicinal species.

Kaempferol

Kaempferol is a biologically important flavanol identified in multiple parts of *S. torvum* Sw., including the leaves, fruits, aerial parts, and roots.[13,36] It has been isolated from fruit extracts using silica gel, Sephadex LH-20, and RP-C18 column chromatography, confirming its widespread distribution within the plant.[37] Although quantitative data for *S. torvum* Sw. remain limited, kaempferol is recognized as a multifunctional phytochemical with broad pharmacological potential. It exhibits potent antioxidant and anti-inflammatory activities by scavenging reactive oxygen species, preserving endogenous antioxidant enzymes, suppressing inflammatory cytokines, inhibiting NF-κB, and activating the Nrf2 signaling pathway.[38,39] Kaempferol also demonstrates significant anticancer activity by inhibiting cell proliferation, inducing apoptosis and cell-cycle arrest, suppressing angiogenesis, metastasis, and epithelial–mesenchymal transition, and modulating key signaling pathways, including PI3K/AKT, Src kinase, and HTLV-I pathways.[40,41] Beyond its anticancer properties, kaempferol has been associated with antimicrobial, cardioprotective, neuroprotective, antidiabetic, anti-osteoporotic, analgesic, anxiolytic, antiallergic, estrogenic/antiestrogenic, and anti-ageing effects, supporting its potential in the prevention and management of several chronic diseases.[39,42] In addition, *in silico* evidence suggests that kaempferol from *S. torvum* Sw. may interact with the SARS-CoV-2 protease, indicating potential antiviral activity.[3] Overall, kaempferol is a promising bioactive constituent contributing to the therapeutic potential of *S. torvum* Sw. However, most mechanistic and pharmacological evidence has been generated from studies on purified kaempferol rather than *S. torvum* Sw. derived kaempferol. Therefore, compound-specific investigations are required to validate its molecular targets, bioavailability, and therapeutic efficacy in this medicinal species.

Rutin

Rutin is a major flavonoid identified in *S. torvum* Sw. fruits, with a reported concentration of 1.36% (w/w) in methanolic extracts quantified by HPLC.[10] Additional analyses have reported rutin contents of 44 ± 1.2 µg/mg in methanolic extracts and 32 ± 0.8 µg/mg in hydroalcoholic extracts, confirming its consistent occurrence in the plant.[43] Rutin exhibits diverse pharmacological activities, primarily through its antioxidant and cytoprotective properties. Recent *in silico* and *in vitro* studies have demonstrated that rutin inhibits aromatase, suggesting therapeutic potential in the management of polycystic ovary syndrome-associated infertility, while also contributing antioxidant and antidiabetic effects.[44] In streptozotocin-induced diabetic rats, *S. torvum* Sw. extracts rich in rutin significantly reduced blood glucose levels by 17.04% and 42.10% at doses of 200 and 400 mg/kg/day, respectively, over 30 days. These effects were associated with cryoprotection and regeneration of pancreatic β-cells, supporting its antidiabetic potential.[10] Furthermore, methanolic and hydroalcoholic extracts containing rutin protected against Monosodium glutamate-induced hepatotoxicity and nephrotoxicity in Wistar rats, primarily through antioxidant mechanisms, although these protective effects were attributed to the combined action of flavonoids and phenolic compounds rather than rutin alone.[43] Collectively, these

findings identify rutin as an important contributor to the pharmacological profile of *S. torvum* Sw. However, except for aromatase inhibition, most biological activities have been evaluated using crude plant extracts rather than isolated rutin. Therefore, further compound-specific studies are required to define its molecular targets, pharmacokinetics, and therapeutic efficacy in *S. torvum* Sw.

Luteolin

Luteolin is a naturally occurring flavone with well-established pharmacological activities, although its occurrence has not yet been reported in *S. torvum* Sw. In other plant species, including *Solanum* (tomato), *Capsicum*, Kalamata olives, and peanut shells, luteolin has been identified in fruits, leaves, and seeds, with reported concentrations of 74 mg/kg fresh weight in Kalamata olives and 3183.58 µg/g dry weight in peanut shells.[45] Extensive pharmacological studies have demonstrated that luteolin possesses potent antioxidant, anti-inflammatory, antimicrobial, antidiabetic, cardioprotective, and antihypertensive activities, primarily through free radical scavenging and attenuation of oxidative stress.[5] In addition, luteolin exhibits broad therapeutic potential against multiple pathological conditions, including cancer, metabolic disorders, cardiovascular diseases, neurodegenerative disorders, asthma, viral infections, and reproductive dysfunction.[45] Its anticancer activity has been extensively validated *in vitro* and *in vivo*, where it suppresses tumor cell proliferation, induces cell-cycle arrest and apoptosis through intrinsic and extrinsic signaling pathways, inhibits topoisomerases I and II, reduces MMP2 and MMP9 activity, lowers prostate-specific antigen levels, and inhibits fatty acid synthesis, with reported IC_{50} values ranging from 3 to 50 µM against several cancer cell lines. Although these findings highlight luteolin as a promising therapeutic flavonoid, its presence, concentration, and pharmacological significance in *S. torvum* Sw. have not yet been established. Therefore, comprehensive phytochemical profiling and bioactivity-guided investigations are required to determine whether luteolin occurs in *S. torvum* Sw. and contributes to its medicinal properties.

Terpenoids, saponins, and tannins

Terpenoids, saponins, and tannins are important classes of secondary metabolites that substantially contribute to the pharmacological potential of *S. torvum* Sw. Among these, steroidal saponins are the most abundant and extensively characterized constituents. More than 30 steroidal saponins, including torvosides, solanolactosides, neochlorogenic derivatives, chlorogenate, diosgenin, and Spirostanol and furstanol glycosides, have been isolated from the fruits, leaves, aerial parts, and whole plant.[2,23,46] These metabolites exhibit a wide range of biological activities, including anti-inflammatory, immunomodulatory, antimicrobial, cytotoxic, and anticancer effects, highlighting their therapeutic potential.[2,6] In addition, *S. torvum* Sw. contains diverse terpenoids, comprising mono-, sesqui-, di-, and triterpenoids, including frolic acid, which are associated with antioxidant, antimicrobial, anti-inflammatory, and hepatoprotective activities.[2,6] Tannins, consistently detected in the fruits and leaves, further contribute to the medicinal value of the plant through their free radical scavenging, metal-chelating, antimicrobial, and astringent properties, thereby reinforcing its antioxidant defense system.[2,6] Collectively, these phytochemical groups act synergistically with flavonoids, phenolic acids, and alkaloids to account for the broad pharmacological activities of *S. torvum* Sw. However, the molecular targets, pharmacokinetic characteristics, and compound-specific therapeutic mechanisms of many terpenoids, saponins, and tannins remain poorly understood. Future studies should therefore focus on bioactivity-guided isolation, mechanistic investigations, and pharmacokinetic evaluation to support their pharmaceutical and phytomedicinal development. The major terpenoids, saponins, and tannins of *S. torvum* Sw. are summarized in Figure 1.

Toxicology and safety

Despite its diverse pharmacological properties, the safety profile of *S. torvum* Sw. remains a critical consideration for its medicinal and nutraceutical applications. The fruits and leaves have long been consumed as food and traditional herbal remedies across Asia and Africa, with no major reports of adverse effects, indicating a favorable safety margin under customary dietary use. Experimental studies further support this traditional evidence, demonstrating that aqueous and ethanolic extracts of *S. torvum* Sw. exhibit low acute toxicity, with no significant mortality, behavioral abnormalities, or treatment-related alterations in hematological, biochemical, and histopathological parameters at pharmacologically effective doses. Repeated administration has also been reported to be well tolerated within the investigated dose ranges, supporting the overall safety of the plant.[2,6,43] However, the presence of biologically active SGAs, particularly solanine and solamargine, necessitates careful dose consideration, as excessive exposure may induce toxicity through membrane-disrupting mechanisms. Moreover, the concentrations of these compounds vary considerably with plant part, developmental stage, genotype, environmental conditions, and processing methods, potentially influencing both therapeutic efficacy and safety.[11,12] Although current evidence suggests that *S. torvum* Sw. is relatively safe within the tested dosage range, comprehensive evaluations of chronic toxicity, reproductive and developmental toxicity, genotoxicity, pharmacokinetics, herb–drug interactions, and long-term clinical safety remain limited. Therefore, standardized toxicological assessments, dose optimization studies, and well-designed clinical trials are essential to establish the safety profile and support the clinical translation of *S. torvum* Sw. based therapeutic formulations.

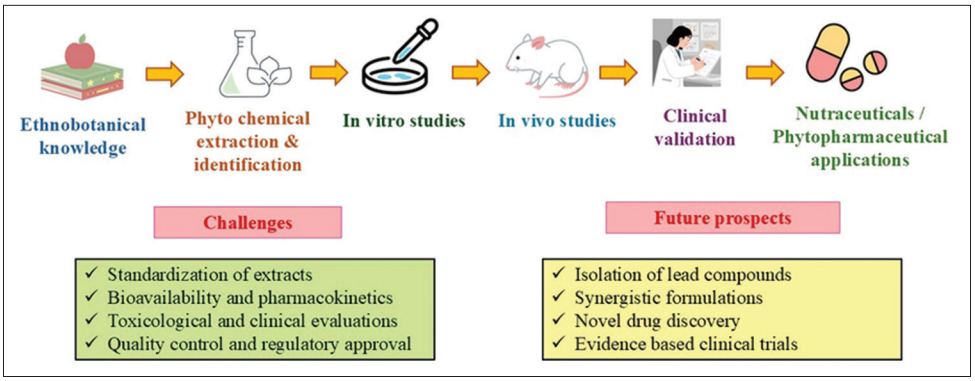


Figure 3: Conceptual framework for the pharmaceutical translation of *Solanum torvum* Sw.

FUTURE PROSPECTS

The translation of *S. torvum* Sw. from a traditional medicinal plant to an evidence-based therapeutic agent requires a multidisciplinary research framework [Figure 3]. Although extensive phytochemical and pharmacological investigations have identified several bioactive constituents with promising biological activities, their clinical application remains limited by inadequate phytochemical standardization, insufficient pharmacokinetic and bioavailability data, limited toxicological evaluation, and a lack of robust clinical evidence. Future research should prioritize bioactivity-guided isolation of lead compounds, standardized extract development, mechanistic validation, and well-designed clinical trials. Integrating phytochemistry, molecular pharmacology, metabolomics, systems biology, and pharmaceutical formulation strategies will accelerate the development of safe, effective, and standardized *S. torvum* Sw. based phytopharmaceuticals and nutraceuticals. The proposed translational framework is illustrated in Figure 3.

CONCLUSION

S. torvum Sw. is a valuable medicinal plant with a diverse repertoire of bioactive phytochemicals, including SGAs, phenolic acids, flavonoids, terpenoids, saponins, and tannins, which collectively underpin its broad pharmacological potential. Current evidence indicates that these metabolites exert antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, cardioprotective, nephroprotective, neuroprotective, and anticancer activities by modulating oxidative stress, inflammation, apoptosis, ferroptosis, and multiple cell-signaling pathways. However, most mechanistic evidence originates from *in vitro* studies, experimental animal models, or investigations using isolated compounds rather than *S. torvum* Sw. derived phytochemicals. Consequently, the precise contribution of individual constituents to the therapeutic efficacy of the plant remains insufficiently defined.

Despite substantial progress in phytochemical characterization, several challenges continue to hinder the pharmaceutical development of *S. torvum* Sw. Quantitative data for many bioactive compounds remain incomplete, while phytochemical variability associated with plant organ, genotype, geographical origin, cultivation practices, and extraction methods has not been systematically addressed. In addition, compound-specific pharmacological validation, molecular target identification, pharmacokinetic and bioavailability studies, metabolomic characterization, and standardized quality control protocols are still limited. The absence of comprehensive chronic toxicity studies, herb–drug interaction assessments, and well-controlled clinical trials further restricts the translation of promising preclinical findings into clinical practice.

Future research should focus on bioactivity-guided isolation, comprehensive metabolomic profiling, and rigorous compound-specific pharmacological investigations to identify the principal therapeutic constituents of *S. torvum* Sw. Integrating transcriptomics, proteomics, metabolomics, molecular docking, network pharmacology, and experimental validation will provide deeper mechanistic insights into its biological activities. Furthermore, standardized extraction methods, quality assurance strategies, pharmacokinetic evaluation, toxicological assessment, and multicenter clinical trials are essential to establish the safety, efficacy, and reproducibility of *S. torvum* Sw. based formulations and facilitate their pharmaceutical development.

Overall, *S. torvum* Sw. represents a promising yet underexplored source of therapeutic phytochemicals with considerable potential for drug discovery, phytopharmaceutical development, nutraceuticals, and functional foods. Addressing the current gaps through multidisciplinary research will accelerate the translation of this traditionally important medicinal plant into scientifically validated, standardized, and clinically relevant therapeutic products.

REFERENCES

1. Yousaf Z, Wang Y, Baydoun E. Phytochemistry and pharmacological studies on *Solanum torvum* Swartz. J Appl Pharm Sci 2013;3:152-60.

2. Kaunda JS, Zhang YJ. The genus *Solanum*: An ethnopharmacological, phytochemical and biological properties review. Nat Prod Bioprospect 2019;9:77-137.
3. Bongo GN, Mutunda CM, Inkoto CL, Mbadiko CM, Lengbiye E, Dorothée TD, *et al*. Review on ethno-botany, virucidal activity, phytochemistry and toxicology of *Solanum* genus: Potential bio-resources for the therapeutic management of covid-19. Eur J Nutr Food Saf 2020;12:35-48.
4. Hussain S, Kumar A, Singh K, Kushwaha SP, Arif M, Mursal M. Phytochemical and biological studies of *Solanum torvum* L. In folklore medicine of Assam. Ann Phytomed 2023;12:1-8.
5. Putri NN, Anggriani R, Sukardi S. Bioactive compound in *Solanum torvum* and its potential as functional food and drink: A review. Biol Med Nat Prod Chem 2023;12:205-13.
6. Garg M, Vaid L, Sharma P, Rani N, Deswal G, Grewal S, *et al*. Explicating the phyto-pharmacological virtues of *Solanum torvum* Swartz: A contemporary update. Nat Prod J 2025;15:E130624231024.
7. Sundari SG, Rekha S, Parvathi A. Phytochemical evaluation of three species of *Solanum* L 2013:420-5.
8. Koomson DA, Kwakye BD, Darkwah WK, Odum B, Asante M. Phytochemical constituents, total saponins, alkaloids, flavonoids and vitamin C contents of ethanol extracts of five *Solanum torvum* fruits. Pharmacogn J 2018;10:946-50.
9. Ramamurthy CH, Kumar MS, Suyavaran VS, Mareeswaran R, Thirunavukkarasu C. Evaluation of antioxidant, radical scavenging activity and polyphenolics profile in *Solanum torvum* L. Fruits. J Food Sci 2012;77:C907-13.
10. Gandhi GR, Ignacimuthu S, Paulraj MG. *Solanum torvum* Swartz. Fruit containing phenolic compounds shows antidiabetic and antioxidant effects in streptozotocin induced diabetic rats. Food Chem Toxicol 2011;49:2725-33.
11. Akiyama R, Umemoto N, Mizutani M. Recent advances in steroidal glycoalkaloid biosynthesis in the genus *Solanum*. Plant Biotechnol (Tokyo) 2023;40:185-91.
12. Li Y, Luo J. From steroidal glycoalkaloids to steroidal saponins: Biosynthesis and ecological role in the *Solanum* genus. Mol Plant 2025;18:22-4.
13. Ganguly P, Chatterjee S, Kumari S, Pati PP, Julekha K. Pharmacognostical, phytochemical and phytopharmacological activities of *Solanum torvum* utilized as a traditional medicinal herb: A review. J Appl Nat Sci 2024;16:1317-34.
14. Khan A, Jahan S, Imtiyaz Z, Alshahrani S, Antar Makeen H, Mohammed Alshehri B, *et al*. Neuroprotection: Targeting multiple pathways by naturally occurring phytochemicals. Biomedicines 2020;8:284.
15. Xiao M, Xu J, Wang W, Zhang B, Liu J, Li J, *et al*. Functional significance of cholesterol metabolism in cancer: From threat to treatment. Exp Mol Med 2023;55:1982-95.
16. Li TC, Chen NJ, Chen YY, He BJ, Zhou ZF. Solasonine induces apoptosis of the SGC-7901 human gastric cancer cell line *in vitro* via the mitochondria-mediated pathway. J Cell Mol Med 2022;26:3387-95.
17. Pham MQ, Tran TH, Pham QL, Gairin JE. *In silico* analysis of the binding properties of solasonine to mortalin and p53, and *in vitro* pharmacological studies of its apoptotic and cytotoxic effects on human HepG2 and Hep3b hepatocellular carcinoma cells. Fundam Clin Pharmacol 2019;33:385-96.
18. Zhang Y, Han G, Cao Y, Zhang Y, Zhang X, Gong H. Solasonine inhibits gastric cancer proliferation and enhances chemosensitivity through microRNA-486-5p. Am J Transl Res 2020;12:3522-30.
19. Jin M, Shi C, Li T, Wu Y, Hu C, Huang G. Solasonine promotes ferroptosis of hepatoma carcinoma cells via glutathione peroxidase 4-induced destruction of the glutathione redox system. Biomed Pharmacother 2020;129:110282.
20. Hu C, Zhang JQ, Zhuang XY, Zhao ZD, Qian XJ, Chen Y. The hidden potential of solasonine: Targeting non-small cell lung cancer (NSCLC) metastasis through GATM and Smad2 pathways. Phytomedicine 2025;139:156455.
21. Kalalinia F, Karimi-Sani I. Anticancer properties of solamargine: A systematic review. Phytother Res 2017;31:858-70.
22. Tang Z, Zhang Y, Li N, Xu L, Zhao B, Xiao W, *et al*. Extraction, purification technology and antineoplastic effects of solamargine. Zhongguo Zhong Yao Za Zhi 2011;36:2192-5.
23. Arthan D, Svasti J, Kittakoop P, Pittayakhachonwut D, Tanticharoen M, Thebtaranonth Y. Antiviral isoflavonoid sulfate and steroidal glycosides from the fruits of *Solanum torvum*. Phytochemistry 2002;59:459-63.
24. Iida Y, Yanai Y, Ono M, Ikeda T, Nohara T. Three unusual 22-β-O-23-hydroxy-(5alpha)-spirostanol glycosides from the fruits of *Solanum torvum*. Chem Pharm Bull (Tokyo) 2005;53:1122-5.
25. Plazas M, Prohens J, Cuñat AN, Vilanova S, Gramazio P, Herraiz FJ, *et al*. Reducing capacity, chlorogenic acid content and biological activity in a collection of scarlet (*Solanum aethiopicum*) and Gboma (*S. macrocarpon*) eggplants. Int J Mol Sci 2014;15:17221-41.
26. Namani S, Paripelli S, Chinni SV, Kasi M, Subramaniam S, Rathinam X. *In vitro* anti-oxidant assay, HPLC profiling of polyphenolic compounds, AAS and FTIR spectrum of Malaysian origin *Solanum torvum* fruit. Indian J Pharm Educ Res 2016;50:S11-20.
27. Kouadio K, Kouadio M, Adingra KM, Kouadio EJ. Antioxidant activities, phenolic compounds and organic acids of raw and boiled berries of *Solanum torvum* Swartz from Eastern Côte d'Ivoire. Indones Food Sci Technol J 2022;6:7-18.
28. Panche AN, Diwan AD, Chandra SR. Flavonoids: An overview. J Nutr Sci 2016;5:e47.
29. Kumar S, Pandey AK. Chemistry and biological activities

of flavonoids: An overview. ScientificWorldJournal 2013;2013:162750.
30. Pietta PG. Flavonoids as antioxidants. J Nat Prod 2000;63:1035-42.
31. Mukunzi P, Byishimo BS, Etukudo EM, Iradukunda H, Benimana D, Usman IM, *et al*. Phytochemical composition and anti-Alzheimer potential of medicinal plants from central and West Africa: Systematic review. Toxicol Rep 2026;16:102205.
32. Aghababaei F, Hadidi M. Recent advances in potential health benefits of quercetin. Pharmaceuticals (Basel) 2023;16:1020.
33. Jan AT, Kamli MR, Murtaza I, Singh JB, Ali A, Haq QM. Dietary flavonoid quercetin and associated health benefits-an overview. Food Rev Int 2010;26:302-17.
34. Chen D, Wang J, Lei Z, Qu L, Zou W. Evidence synthesis and mechanism analysis of quercetin treatment for atherosclerosis: A preclinical systematic review and meta-analysis. Int J Mol Sci 2026;27:527.
35. Díaz-Romero C, Heras-Roger J, Rincón-Cervera MÁ, Guil-Guerrero JL. Wild edible fruits: A structured narrative review on bioactive composition and bioactivity. Foods 2026;15:1106.
36. Nesari T, Kajaria D, Prasanth D, Thakur M, Arun NK, Pathak A, *et al*. Clinical-molecular assessment of guduchyadi tablet treatment in seven mild COVID-19 patients: A pilot study. J Herb Med 2026;58:101120.
37. Pandey G, Prajapati KK, Pandey R. Distribution, taxonomy and medicinal importance of *Solanum torvum* Sw. PhytoTalks 2024;1:95-105.
38. Rajendran P, Rengarajan T, Nandakumar N, Palaniswami R, Nishigaki Y, Nishigaki I. Kaempferol, a potential cytostatic and cure for inflammatory disorders. Eur J Med Chem 2014;86:103-12.
39. Imran M, Salehi B, Sharifi-Rad J, Aslam Gondal T, Saeed F, Imran A, *et al*. Kaempferol: A key emphasis to its anticancer potential. Molecules 2019;24:2277.
40. Chen AY, Chen YC. A review of the dietary flavonoid, kaempferol on human health and cancer chemoprevention. Food Chem 2013;138:2099-107.
41. Imran M, Rauf A, Shah ZA, Saeed F, Imran A, Arshad MU, *et al*. Chemo-preventive and therapeutic effect of the dietary flavonoid kaempferol: A comprehensive review. Phytother Res 2019;33:263-75.
42. Calderón-Montaño JM, Burgos-Morón E, Pérez-Guerrero C, López-Lázaro M. A review on the dietary flavonoid kaempferol. Mini Rev Med Chem 2011;11:298-344.
43. Kadam V, Gangurde S, Mohan M. Protective effect of *Solanum torvum* on monosodium glutamate-induced hepatotoxicity and nephrotoxicity in rats. Indian J Nat Prod Resour 2019;10:31-42.
44. Choudhury AA, Bhattarai A, Sahoo S, Roy SD, Laskar NA, Firoz A. *In Silico* drug discovery of *Solanum torvum* as a phytotherapeutic aromatase inhibitor for PCOS-induced infertility: A comparative study with FDA-approved drugs. Silico Res Biomed 2025;1:100003.
45. Zhu M, Sun Y, Su Y, Guan W, Wang Y, Han J, *et al*. Luteolin: A promising multifunctional natural flavonoid for human diseases. Phytother Res 2024;38:3417-43.
46. Lee CL, Hwang TL, He WJ, Tsai YH, Yen CT, Yen HF, *et al*. Anti-neutrophilic inflammatory steroidal glycosides from *Solanum torvum*. Phytochemistry 2013;95:315-21.

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